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Gibbs

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(54) **CONTROLLED RECTIFIER BRIDGE, CONTROL SYSTEM, AND METHOD FOR CONTROLLING RECTIFIER BRIDGE BY DISABLING GATE CONTROL SIGNALS**

6,208,120 B1 3/2001 Gibbs
6,232,751 B1 5/2001 Farr et al.
6,791,852 B1 * 9/2004 Carter et al. 363/57

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(52) **U.S. Cl.** **307/151; 307/127; 363/87**
(58) **Field of Classification Search** **363/87; 307/127, 151**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,142,151 A * 2/1979 Hansen 324/767
4,633,241 A * 12/1986 Casteel et al. 340/645
5,963,440 A 10/1999 Gibbs et al.
5,963,441 A 10/1999 Gibbs et al.
6,046,917 A 4/2000 Gibbs et al.

OTHER PUBLICATIONS

“Active current balance between parallel thyristors in multi-bridge AC-DC rectifiers,” Gibbs, I.A.; Kimmel, D.S.; Energy Conversion, IEEE Transactions on vol. 16, Issue 4, Dec. 2001 pp. 334-339, Manuscript received Jun. 22, 2001.*

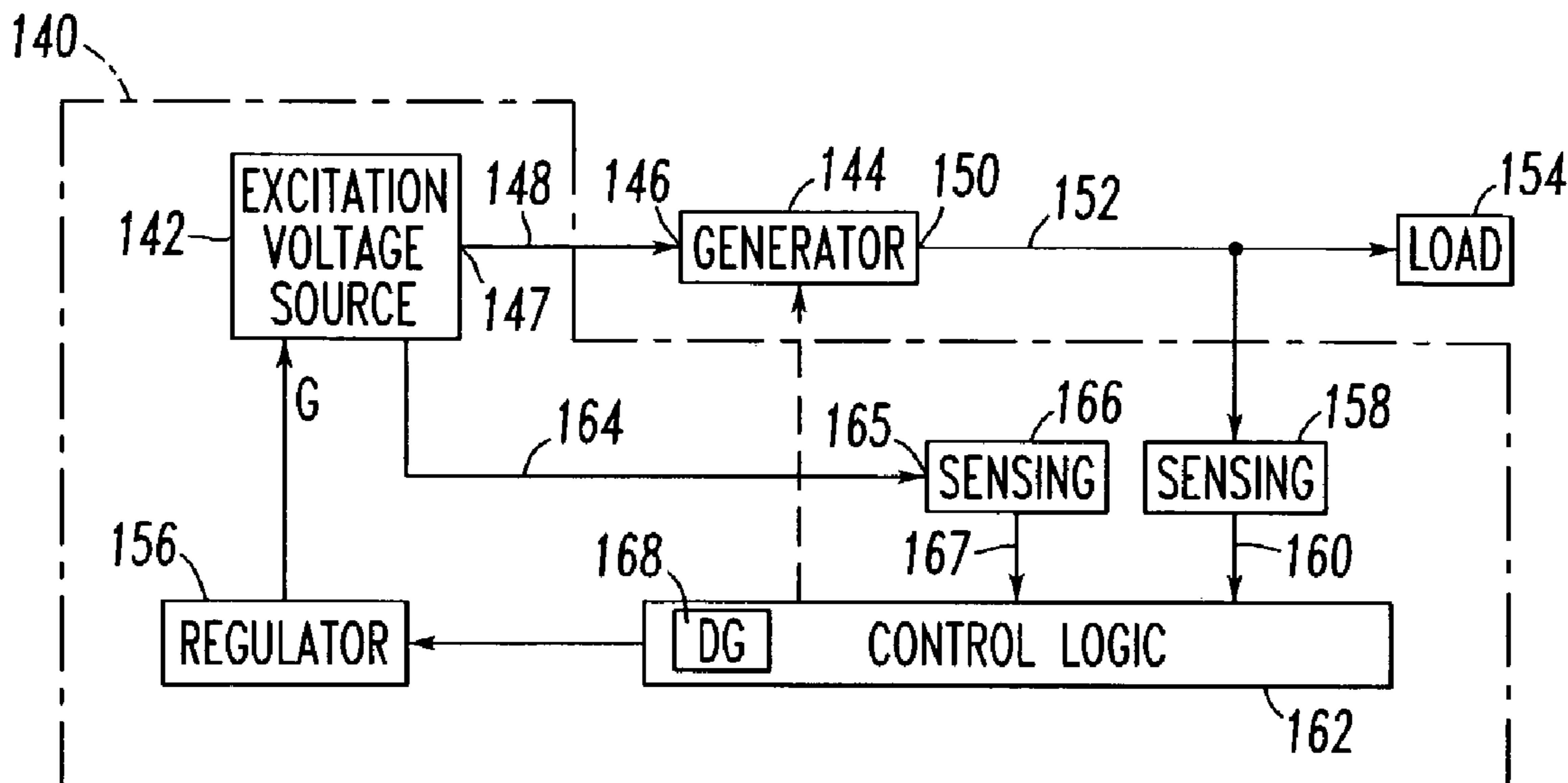
* cited by examiner

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(57) **ABSTRACT**

A controlled rectifier bridge includes a plurality of segments each having an element responsive to a control signal, and an output having a voltage, a first current and a second current. Sensors provide sensed current values from first and second output currents from the bridge. A routine determines if the sensed current values are greater than a predetermined value. A regulator outputs the control signals to the segments in order to control current conduction within the segments. A routine determines if a circuit interrupter is open or if current is not flowing between bridge inputs and the corresponding alternating current phases. A routine disables the control signals to pairs of the segments when the sensed current values are greater than the predetermined value, and when the circuit interrupter is open or when current is not flowing between the inputs and the corresponding alternating current phases.

15 Claims, 4 Drawing Sheets



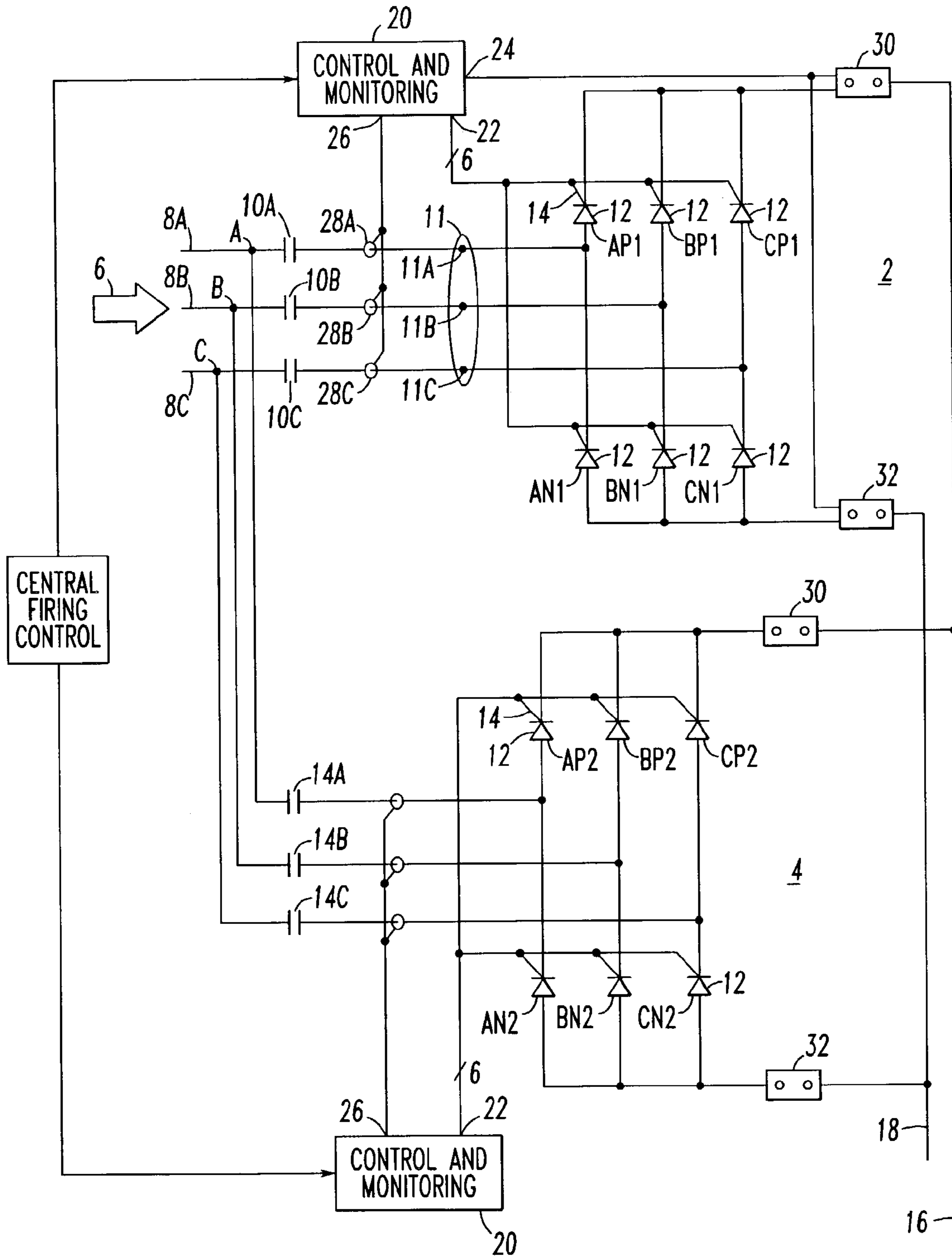


FIG. 1
PRIOR ART

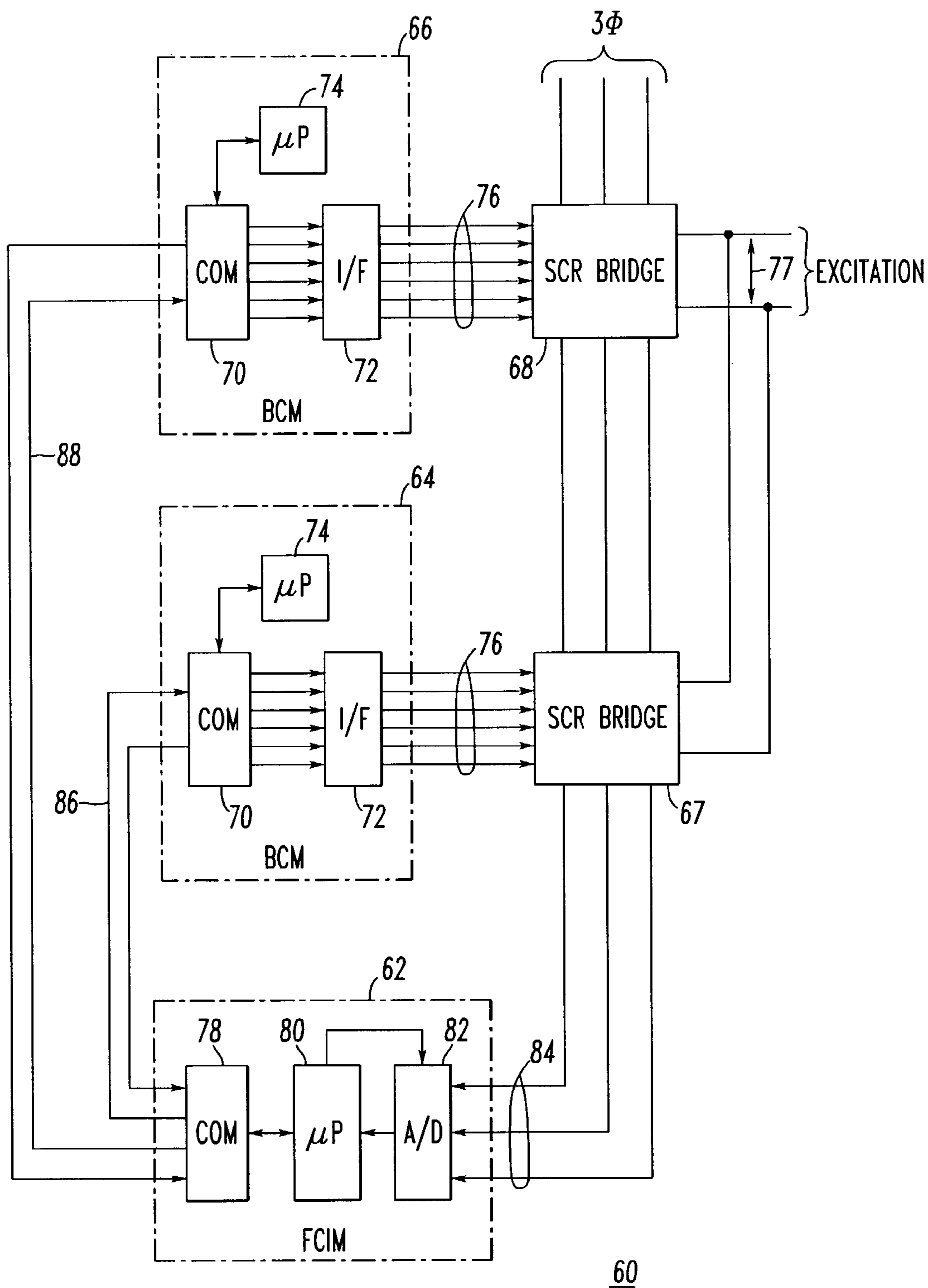


FIG. 2
PRIOR ART

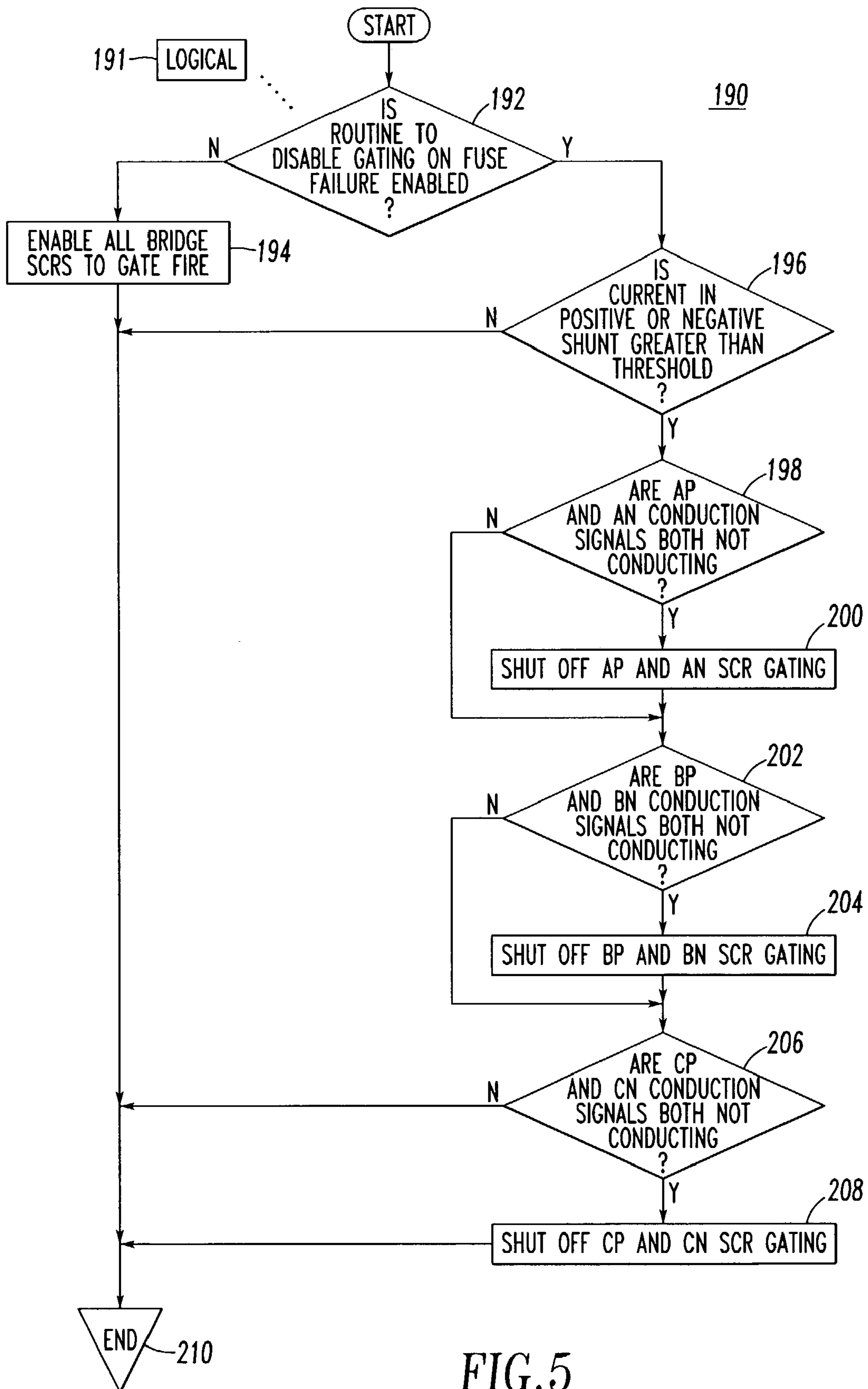


FIG. 5

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**CONTROLLED RECTIFIER BRIDGE,
CONTROL SYSTEM, AND METHOD FOR
CONTROLLING RECTIFIER BRIDGE BY
DISABLING GATE CONTROL SIGNALS**

**CROSS-REFERENCE TO RELATED
APPLICATION**

This application is related to commonly assigned, co-
pending U.S. patent application Ser. No. 10/159,887, filed
May 30, 2002, entitled "Control System Including Rectifier
and Method for Controlling Rectifier Bridge by Disabling
Gating of Semiconductor Device Based Upon Heat Sink or
Junction Temperature".

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to control systems and, more
particularly, to control of rectifiers employing semiconduc-
tor devices, such as silicon controlled rectifiers (SCRs) or
thyristors. The invention also relates to a method for con-
trolling a rectifier bridge.

2. Background Information

Three-phase rectifier circuits are commonly employed to
convert AC signals to DC signals. These circuits often use
SCRs disposed in bridge segments, with typically one SCR
for each polarity of each AC phase. Typically, a bridge firing
control circuit controls the firing point for each rectifier in
each AC cycle. Examples of such circuits are disclosed in
U.S. Pat. Nos. 5,963,440; 5,963,441; 6,046,917; 6,208,120;
and 6,232,751.

It is not uncommon for a plurality of SCR bridges to be
operated in parallel with each of the corresponding bridge
firing control circuits being controlled by a central firing
control circuit. The central firing control circuit manages
each of the bridge firing control circuits in order that the
corresponding rectifiers in each of the parallel bridges
conduct current at the same point in the AC waveform.

SCR bridges are commonly employed in an excitation
control system to provide field excitation for a rotating
electrical apparatus (e.g., large synchronous generators and
motors, utility synchronous generators and motors, indus-
trial synchronous motors and generators, synchronous gen-
erators and motors for naval or other shipping applications,
synchronous generators and motors for oil well drilling
rigs).

Traditionally, fuses are employed in series with each one
of the semiconductor devices (e.g., six total thyristors or
SCRs) in a full-wave (e.g., six-pulse) bridge, in order to
protect the bridge and the semiconductor devices from
faults. A bridge converter may include two or more parallel
bridges. Each one of these bridges is configured in parallel
with the other one or more bridges, in order that they share
the load current. Furthermore, one or two fuses may be
employed between the DC output of each one of the bridges
and the load.

Using only AC line fuses (e.g., three total for a three-
phase power source) on converter bridges reduces the num-
ber of fuses required and generally protects both the AC bus
and the DC bus. However, other problems may result.

When the load is inductive, the instantaneous output of
the bridge (i.e., the load voltage) may be negative during
certain intervals (although the load current is generally
constant through the inductive load). If AC line fuses are
employed, and if a semiconductor device (e.g., thyristor) is
shorted (i.e., failed), then a path for current is provided

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through the shorted thyristor when the conjugate (i.e., series)
thyristor is gated. This is because the negative voltage may
be present across the load and, hence, current would then
flow through the shorted thyristor when the conjugate thrysi-
tor is fired. This is unacceptable because continued operation
may result in the conjugate thyristor failing if it carries too
much current. Also, the converter bridge cannot develop full
negative voltage.

Accordingly, there is room for improvement in controlled
rectifier bridges, control systems, and methods for control-
ling rectifier bridges.

SUMMARY OF THE INVENTION

These needs and others are met by the present invention,
which disables control signals to elements or semiconductor
devices, such as a thyristors or SCRs, of a rectifier bridge.
This is accomplished by detecting an open circuit inter-
rupter, such as an AC line fuse, for a particular rectifier
bridge and, then, responsively removing control signals
from two series elements (e.g., a potentially shorted thyristor
and the conjugate (series) thyristor). This solves the problem
of the potentially shorted thyristor because the conjugate
thyristor remains in a blocking state and does not allow
conduction. Hence, such conjugate thyristor does not over-
heat.

The invention disables the control signals to the two
elements, which are fed by a corresponding circuit inter-
rupter, such as an AC line fuse, when either one of those two
elements is shorted. The fuse may open, for example, in
response to an output short circuit condition, a defective
thyristor, or an overheated thyristor. This removes the path
for current through the conjugate element, which is in series
with the shorted element, and allows the rectifier bridge or
converter to maintain its normal output.

As one aspect of the invention, a controlled rectifier
bridge converts a plurality of alternating current voltages
from a plurality of alternating current phases to a voltage,
each of the alternating current phases has a positive polarity
and a negative polarity, the controlled rectifier bridge com-
prises: a plurality of segments, each of the segments having
an element responsive to a control signal; an output having
the voltage, a first current and a second current; at least one
sensor providing at least one sensed current value from the
first current or the second current of the output; means for
determining if the at least one sensed current value is greater
than a predetermined value; means for outputting the control
signals to the segments in order to control current conduc-
tion within the segments; and for each of the alternating
current phases: an input electrically interconnected with a
corresponding one of the alternating current phases, a circuit
interrupter electrically connected in series with the input, a
first one of the segments for the positive polarity of the
corresponding one of the alternating current phases, a sec-
ond one of the segments for the negative polarity of the
corresponding one of the alternating current phases, the
second one of the segments for the negative polarity of the
corresponding one of the alternating current phases in series
with the first one of the segments for the positive polarity of
the corresponding one of the alternating current phases,
means for determining if the circuit interrupter is open or if
current is not flowing between the input and the correspond-
ing one of the alternating current phases, and means for
disabling the control signals to the first one and the second
one of the segments when the at least one sensed current
value is greater than the predetermined value, and when the

circuit interrupter is open or when current is not flowing between the input and the corresponding one of the alternating current phases.

As another aspect of the invention, a method controls a rectifier bridge to convert a plurality of alternating current voltages from a plurality of alternating current phases to a voltage, each of the alternating current phases has a positive polarity and a negative polarity, the rectifier bridge includes a plurality of segments, each of the segments has an element responsive to a control signal, the rectifier bridge also includes an output having the voltage, a first current, a second current, and, for each of the alternating current phases, an input electrically interconnected with a corresponding one of the alternating current phases, a circuit interrupter electrically connected in series with the input, a first one of the segments for the positive polarity of the corresponding one of the alternating current phases, and a second one of the segments for the negative polarity of the corresponding one of the alternating current phases, the second one of the segments for the negative polarity of the corresponding one of the alternating current phases in series with the first one of the segments for the positive polarity of the corresponding one of the alternating current phases, the method comprises: sensing at least one sensed current value from the first current or the second current of the output; determining if the at least one sensed current value is greater than a predetermined value; outputting the control signals to the segments in order to control current conduction within the segments; determining if one of the circuit interrupters is open or if current is not flowing between the input and the corresponding one of the alternating current phases; and disabling the control signals to the first one and the second one of the segments responsive to: (a) the at least one sensed current value being greater than the predetermined value, and (b) the one of the circuit interrupters is open or current is not flowing between the input and the corresponding one of the alternating current phases.

As another aspect of the invention, a control system comprises: a first rectifier bridge; a second rectifier bridge; a circuit controlling the first and second rectifier bridges; each of the first and second rectifier bridges converting a plurality of alternating current voltages from a plurality of alternating current phases to a voltage, each of the alternating current phases having a positive polarity and a negative polarity, each of the first and second rectifier bridges comprises: a plurality of segments, each of the segments having an element responsive to a control signal; an output having the voltage, a first current and a second current; a first sensor providing a first sensed current value from the first current, a second sensor providing a second sensed current value from the second current, means for determining if the first sensed current value or the second sensed current value is greater than a predetermined value; means for outputting the control signals to the segments in order to control current conduction within the segments; and for each of the alternating current phases: an input electrically interconnected with a corresponding one of the alternating current phases, a circuit interrupter electrically connected in series with the input, a first one of the segments for the positive polarity of the corresponding one of the alternating current phases, a second one of the segments for the negative polarity of the corresponding one of the alternating current phases, the second one of the segments for the negative polarity of the corresponding one of the alternating current phases in series with the first one of the segments for the positive polarity of the corresponding one of the alternating current phases, means for determining if the circuit interrupter is open or if

current is not flowing between the input and the corresponding one of the alternating current phases, and means for disabling the control signals to the first one and the second one of the segments when the first sensed current value or the second sensed current value is greater than the predetermined value, and when the circuit interrupter is open or when current is not flowing between the input and the corresponding one of the alternating current phases.

BRIEF DESCRIPTION OF THE DRAWINGS

A full understanding of the invention can be gained from the following description of the preferred embodiments when read in conjunction with the accompanying drawings in which:

FIG. 1 is a circuit block diagram of two, three-phase, SCR bridges which are fed from a common three-phase source and are connected in parallel to provide an additive current output.

FIG. 2 is a block diagram of a firing control interface module (FCIM) and two bridge control modules (BCMs).

FIG. 3 is a block diagram of an excitation control system in accordance with the present invention.

FIG. 4 is a block diagram of an excitation control system including a rectifier circuit in accordance with the present invention.

FIG. 5 is a block diagram of a routine employed for disabling gate control signals to a pair of thyristors in accordance with an embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is described in association with a bridge rectifier for an excitation control system, although the invention is applicable to a wide range of controlled rectifier bridges, control systems and methods for controlling rectifier bridges.

Bridges of semiconductor controlled rectifiers (SCRs) or thyristors are generally employed to convert alternating current (AC) sinusoidal signal waveforms to direct current (DC). As shown in FIG. 1, two controlled rectifier bridges 2,4 are connected in parallel. Each of the bridges 2,4 receives a multi-phase current input from a common AC source 6 (e.g., a motor generator, field transformer, power potential transformer (PPT)). A three-phase current input is employed in this example, although the invention is applicable to a wide range of phase counts. The several phases of input current, shown as 8A, 8B and 8C, are fed through contacts (e.g., circuit interrupter separable contacts; fuses) 10A, 10B and 10C, and 14A, 14B and 14C, respectively, to rectifying segments on the two respective bridges 2,4. As shown with the bridge 2, three inputs 11, including 11A, 11B, 11C, are electrically interconnected with corresponding alternating current phases A,B,C by the contacts 10A, 10B, 10C, respectively.

The exemplary bridges 2,4 each have six cells or segments, one for each polarity of each of the phase currents 8A, 8B, 8C, although the invention is applicable to a wide range of segment counts. For example, segment AP1 refers to the positive polarity of phase A in the first bridge 2, while segment AN1 refers to the negative polarity of phase A in that first bridge 2. The remaining segments of the first and second bridges 2,4 are noted in a similar manner by reference characters BP1, BN1, CP1, CN1 and AP2, AN2, BP2, BN2, CP2, CN2.

Each bridge segment includes its own element, such as the exemplary SCR **12**, that has a firing input (or gate) **14**. When a suitable control signal is provided to one of the inputs **14**, the corresponding SCR fires to, thereby, control current conduction (e.g., by starting or initiating current conduction) within the corresponding segment. Typically, the individual segments of each of the bridges **2,4** are fired every 60° of the AC cycle in the order: APn, CNn, BPn, ANn, CPn, BNn (where, for convenience of reference, APn, for example, refers to either AP1 or AP2). One of the SCRs **12** does not stop conducting until it is reversed biased. All of the positive rectifier output currents are summed together and the negative rectifier output currents are similarly summed and conveyed by corresponding positive and negative conductors **16,18** to a load (not shown). Typically, the bridges **2,4** include one or more heat sinks (not shown) for the SCRs **12**.

An exemplary microprocessor-based control and monitoring circuit **20** has six control outputs **22**, which are interconnected with the six firing inputs **14** of the SCRs **12**, for outputting control signals to the segments AP1, BP1, CP1, AN1, BN1, CN1 to control current conduction within those segments, and various monitoring inputs **24,26**. The six control outputs **22** include six digital logic control signals each of which controls current conduction within a corresponding one of the segments. The circuit **20** employs a firing code that has six bits. Each of the six bits is set when a corresponding segment is to fire (e.g., bit **0** for APn, bit **1** for BPn, bit **2** for CPn, bit **3** for ANn, bit **4** for BNn, and bit **5** for CNn). Each time a firing occurs, two cells are fired. Also, a cell is usually fired a second time in order that the second firing occurs in the next subsequent firing (e.g., by first firing APn and CNn with the firing code=100001₂, followed by firing CNn and BPn with the firing code=100010₂).

Monitors **28A,28B,28C** provide conduction monitor signals to the inputs **26** for the three AC phases A,B,C. The monitors **28A,28B,28C** monitor the respective phases A,B,C to provide corresponding conduction signals. The control and monitoring circuits **20** also input current signals from the shunts **30,32** and use that information to control the output of the respective bridges **2,4** through DC contact actuators (not shown). As shown with the bridge **2**, the shunt **30**, a first current sensor, for the positive output of the bridge **2**, senses current passing through the segments AP1, BP1, CP1 for the positive polarity of the AC phases A,B,C. Similarly, the shunt **32**, a second current sensor, for the negative output of the bridge **2**, senses current passing through the segments AN1, BN1, CN1 for the negative polarity of the AC phases A,B,C. In turn, the sensors **30,32** provide corresponding current signals to the two inputs **24** of the control and monitoring circuit **20**.

As disclosed in U.S. Pat. No. 5,963,441, preferably, the monitors **28A,28B,28C** are conduction monitors which output conduction monitor signals as four-state logic signals having a first state (e.g., 10₂) representative of the positive polarity of the AC input current **8A,8B,8C**; a second state (e.g., 01₂) representative of the negative polarity of the AC input current; a third state (e.g., 00₂) representative of about zero AC input current; and a fourth state (e.g., 11₂) representative of failure of the monitor. Alternatively, the conduction monitors **28A,28B,28C** are current sensing mechanisms, such as current transformers, which output a first state (e.g., a first range of positive values) of the conduction signal representative of the positive polarity of the AC input current, and a second state (e.g., a second range of negative values) of the conduction signal representative of the negative polarity of the AC input current. In this embodiment, a

control and monitoring circuit (not shown) inputs the three analog conduction signals at the three corresponding inputs, converts those analog inputs to plural-bit digital form (e.g., through a suitable n-bit analog-to-digital converter), and then converts the digital representation of the analog conduction signal to the first state (e.g., 10₂, which is representative of positive AC input current), the second state (e.g., 01₂, which is representative of negative AC input current), or the third state (e.g., 00₂, which is representative of about zero AC input current plus or minus a suitable deadband). It will be appreciated that since the exemplary control and monitoring circuit **20** for bridge **2** employs four-state logic signals, and need not perform analog-to-digital conversions, that a simpler and more economical circuit is possible. It will be appreciated that a wide range of alternative conduction monitors may be employed (e.g., a current sensor; a shunt with a suitable isolation device to provide a suitable sensed current value).

FIG. **2** is a block diagram of a control system **60** including a firing control interface module (FCIM) **62** and two bridge control modules (BCMs) **64,66** for respective SCR bridges **67,68**. Each of the BCMs **64,66** includes a suitable communications interface (COM) **70**, an interface (I/F) **72** to the corresponding bridge **67,68**, and a suitable microprocessor (μ P) **74**. The COM **70** and μ P **74** cooperate to send six exemplary firing pulses **76** to all of the segments in the corresponding bridge **67,68**. The SCR bridges **67,68** output a rectified voltage **77**.

The SCR bridge **67**, for example, has its own BCM **64**, which communicates with the FCIM **62**. The FCIM **62** monitors the input voltage to the bridges **67,68** and also communicates with the other BCM **66**. Although two exemplary bridges **67,68** are shown, one, three, or more parallel bridges may be employed. It will be appreciated that the FCIM **62** controls and communicates with additional bridges in a similar manner.

The FCIM **62** includes a suitable communications interface (COM) **78**, a suitable microprocessor (μ P) **80**, and an A/D converter **82** which samples the voltages of the three phases **84** through a suitable interface (not shown). The COM **78** of the FCIM **62** communicates with the COMs **70** of the BCMs **64,66** through suitable communication channels **86,88**, respectively. In this manner, the FCIM **62** controls the BCMs **64,66** through the corresponding communication channels.

FIG. **3** shows an excitation control system **140** including an excitation voltage source, such as a rectifier bridge **142**. Examples of an excitation control system are disclosed in U.S. Pat. Nos. 6,208,120; and 6,232,751, which are incorporated by reference herein. The exemplary excitation control system **140** is for a rotating electrical apparatus, such as the exemplary generator **144**. The generator **144** includes an input **146** responsive to an excitation voltage source output **147** having an excitation voltage **148**, and an output **150** having one or more alternating current phases **152**, each having a current flowing therein and a voltage, which supply power to a load **154**. One or more circuit breakers (not shown) may be disposed between the generator **144** and the load **154**. The excitation voltage source **142** provides the excitation voltage **148** to the input **146** of the generator **144**. A regulator, such as a bridge control circuit **156** adapted to control the source **142**, regulates the excitation voltage **148**. A first sensing sub-system **158** for the alternating current phases **152** senses generator current and/or generator voltage and provides an electrical signal **160** (e.g., generator line current, generator watts) to control logic **162** for the regulator **156** and generator **144**.

The excitation control system **140** employs the excitation voltage source **142**, which in the exemplary embodiment is a three-phase rectifier circuit, to convert alternating current (AC) sinusoidal signal waveforms to direct current (DC). The three-phase rectifier circuit **142** includes a plurality of semiconductor devices, such as thyristors or SCRs. The semiconductor devices are disposed in bridge segments, with typically one thyristor or SCR for each polarity of each AC phase. The regulator **156** includes a bridge firing control circuit (not shown) to control the firing point for each thyristor or SCR in each AC cycle.

The excitation voltage source **142** has an AC input **164**, which is connected to an input **165** of a suitable sensing circuit **166**, which provides conduction monitor sensor signals **167** to the control logic **162**. In accordance with the invention, a circuit (DG) **168** disables gating (G) of pairs of the semiconductor devices (e.g., AP1,AN1 of FIG. 1; **174**, **182** of FIG. 4) when the output current of the excitation voltage source **142** is greater than a predetermined value, and when current is not flowing between the AC input **164** of the voltage source **142** and the corresponding AC phase (e.g., A,B,C of FIG. 1).

FIG. 4 shows a control system **170** including three-phase AC lines **172**, and a converter including three rectifier bridges, each including six thyristors (i.e., 18 thyristors total) and three fuses (i.e., 9 fuses total). When a thyristor, such as AP3 **174**, shorts, the resulting fault current causes the corresponding circuit interrupter, such as fuse **176**, to open. The present invention detects the open state of the fuse **176** (or the absence of current to or from, e.g., the AC line **172A**) and responsively causes the gate control signals **178** and **180** to the thyristors AP3 **174** and AN3 **182**, respectively, to be disabled (D). Hence, the thyristor anode-cathode voltage is blocked in both the forward and reverse directions at all times. This removes the freewheeling path (e.g., I_F) for current through the pair of thyristors **174,182**. Furthermore, because the converter includes two or more bridges (e.g., three in this example), the proper DC output is maintained.

FIG. 5 shows a routine **190** in accordance with the present invention for execution by the microprocessor of a bridge control module (e.g., **64** or **66** of FIG. 2). The routine **190** is enabled by a logical signal **191**. When the logical signal **191** is "false," then all of the SCRs (e.g., **12** of FIG. 1) are enabled at **194**. Preferably, the logical signal **191** is set "false" whenever the one or more bridges are shut down, and is set "true" (i.e., turned on), when the one or more bridges are turned back on.

On the other hand, if the logical signal **191** is "true" at **192**, then even steps **196–208** determine whether conjugate pairs (e.g., AP1-AN1; BP1-BN1; CP1-CN1) of the SCRs are to be shut off or disabled. At **196**, it is determined if the current in the positive shunt (e.g., **30** of FIG. 1) or the negative shunt (e.g., **32** of FIG. 1) is greater than a predetermined threshold. For example, the predetermined threshold may be 500 A and, depending upon the gain of the transducer, this could be an integer (e.g., 1000 counts). Preferably, the predetermined threshold may be adjusted to accommodate a wide range of converters and load applications. Preferably, the positive and negative shunt currents are filtered. A suitable adjustable filter (not shown) provides a suitable time constant (e.g., about 50 ms to about 100 ms). Normally, for a one-bridge system, these positive and negative shunt currents are equal. However, for a plural-bridge system, the positive shunt current may be different than the negative shunt current for a particular bridge.

If the current in the positive shunt or the (absolute value of the) current in the negative shunt is greater than the

predetermined threshold at **196**, then, at **198**, it is determined if the AP and AN conduction signals are both not conducting. For example, the conduction monitor **28A** of FIG. 1 may provide a state (e.g., 00_2) representative of about zero AC input current through the circuit interrupter contact **10A**. If so, then at **200**, the gate control signals for both AP and AN SCRs are shut off or disabled. If not, or after **200**, execution resumes at **202**.

At **202**, it is determined if the BP and BN conduction signals are both not conducting. For example, the conduction monitor **28B** of FIG. 1 may provide a state (e.g., 00_2) representative of about zero AC input current through the circuit interrupter contact **10B**. If so, then at **204**, the gate control signals for both BP and BN SCRs are shut off or disabled. If not, or after **204**, execution resumes at **206**.

At **206**, it is determined if the CP and CN conduction signals are both not conducting. For example, the conduction monitor **28C** of FIG. 1 may provide a state (e.g., 00_2) representative of about zero AC input current through the circuit interrupter contact **10C**. If so, then at **208**, the gate control signals for both CP and CN SCRs are shut off or disabled. If not, or after **194** or **208**, the routine **190** exits at **210**. Preferably, the routine **190** is periodically executed (e.g., about every 1 ms), in order to provide continuous protection to the converter bridge.

There may be intervals when the two conduction monitor signals of any of the conduction monitors **28A,28B,28C** may both not conduct in a bridge without a blown fuse or open circuit interrupter. For example, if skip fire is active in a bridge, then it is possible that CN and CP, or BN and BP, or AP and AN are not conducting. As a further example, a conduction monitor signal may be considered to be "not conducting" when it has missed conduction for a time period of several cycles. As a still further example, this time period may also be adjustable and is normally set for about 4 to 6 cycles at 60 Hz.

Although conduction monitors **28A,28B,28C** are disclosed, any suitable circuit (e.g., without limitation, blown fuse indicator contacts; circuit interrupter auxiliary contacts), which detects an open circuit condition of the circuit interrupter fuses or contacts, such as **10A,10B,10C**, may be employed.

While specific embodiments of the invention have been described in detail, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention which is to be given the full breadth of the claims appended and any and all equivalents thereof.

What is claimed is:

1. A controlled rectifier bridge for converting a plurality of alternating current voltages from a plurality of alternating current phases to a voltage, each of said alternating current phases having a positive polarity and a negative polarity, said controlled rectifier bridge comprising:

- a plurality of segments, each of said segments having an element responsive to a control signal;
- an output having said voltage, a first current and a second current;
- at least one sensor providing at least one sensed current value from the first current or the second current of said output;
- means for determining if the at least one sensed current value is greater than a predetermined value;

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means for outputting the control signals to said segments in order to control current conduction within said segments; and

for each of said alternating current phases:

an input electrically interconnected with a corresponding one of said alternating current phases,

a circuit interrupter electrically connected in series with said input,

a first one of said segments for the positive polarity of the corresponding one of said alternating current phases,

a second one of said segments for the negative polarity of the corresponding one of said alternating current phases, said second one of said segments for the negative polarity of the corresponding one of said alternating current phases in series with said first one of said segments for the positive polarity of the corresponding one of said alternating current phases,

means for determining if the circuit interrupter is open or if current is not flowing between the input and the corresponding one of said alternating current phases, and

means for disabling the control signals to said first one and said second one of said segments when the at least one sensed current value is greater than the predetermined value, and when the circuit interrupter is open or when current is not flowing between the input and the corresponding one of said alternating current phases.

2. The controlled rectifier bridge of claim 1 wherein said element is a semiconductor device.

3. The controlled rectifier bridge of claim 2 wherein said semiconductor device is a thyristor or SCR.

4. The controlled rectifier bridge of claim 1 wherein said voltage of said output is a direct current voltage.

5. The controlled rectifier bridge of claim 1 wherein said first current equals said second current; and wherein said at least one sensor is a sensor providing a sensed current value from the first current or the second current of said output.

6. The controlled rectifier bridge of claim 1 wherein said first current is different from said second current; and wherein said at least one sensor is a pair of sensors providing a pair of sensed current values from the first current and the second current of said output.

7. A method for controlling a rectifier bridge to convert a plurality of alternating current voltages from a plurality of alternating current phases to a voltage, each of said alternating current phases having a positive polarity and a negative polarity, said rectifier bridge including a plurality of segments, each of said segments having an element responsive to a control signal, said rectifier bridge also including an output having said voltage, a first current, a second current, and, for each of said alternating current phases, an input electrically interconnected with a corresponding one of said alternating current phases, a circuit interrupter electrically connected in series with said input, a first one of said segments for the positive polarity of the corresponding one of said alternating current phases, and a second one of said segments for the negative polarity of the corresponding one of said alternating current phases in series with said first one of said segments for the positive polarity of the corresponding one of said alternating current phases, said method comprising:

sensing at least one sensed current value from the first current or the second current of said output;

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determining if the at least one sensed current value is greater than a predetermined value;

outputting the control signals to said segments in order to control current conduction within said segments;

determining if one of the circuit interrupters is open or if current is not flowing between the input and the corresponding one of said alternating current phases; and disabling the control signals to said first one and said second one of said segments responsive to: (a) the at least one sensed current value being greater than the predetermined value, and (b) said one of the circuit interrupters is open or current is not flowing between the input and the corresponding one of said alternating current phases.

8. The method as recited in claim 7 further comprising employing said first current equal to said second current; and

providing a sensed current value from the first current or the second current of said output.

9. The method as recited in claim 7 further comprising employing said first current different from said second current;

providing a first sensed current value from the first current; and

providing a second sensed current value from the second current.

10. A control system comprising:

a first rectifier bridge;

a second rectifier bridge;

a circuit controlling said first and second rectifier bridges; each of said first and second rectifier bridges converting a plurality of alternating current voltages from a plurality of alternating current phases to a voltage, each of said alternating current phases having a positive polarity and a negative polarity, each of said first and second rectifier bridges comprising:

a plurality of segments, each of said segments having an element responsive to a control signal;

an output having said voltage, a first current and a second current;

a first sensor providing a first sensed current value from the first current,

a second sensor providing a second sensed current value from the second current,

means for determining if the first sensed current value or the second sensed current value is greater than a predetermined value;

means for outputting the control signals to said segments in order to control current conduction within said segments; and

for each of said alternating current phases:

an input electrically interconnected with a corresponding one of said alternating current phases,

a circuit interrupter electrically connected in series with said input,

a first one of said segments for the positive polarity of the corresponding one of said alternating current phases,

a second one of said segments for the negative polarity of the corresponding one of said alternating current phases, said second one of said segments for the negative polarity of the corresponding one of said alternating current phases in series with said first one of said segments for the positive polarity of the corresponding one of said alternating current phases,

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means for determining if the circuit interrupter is open or if current is not flowing between the input and the corresponding one of said alternating current phases, and

means for disabling the control signals to said first one and said second one of said segments when the first sensed current value or the second sensed current value is greater than the predetermined value, and when the circuit interrupter is open or when current is not flowing between the input and the corresponding one of said alternating current phases.

11. The control system of claim **10** wherein said element is a semiconductor device.

12. The control system of claim **11** wherein said semiconductor device is a thyristor or SCR.

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13. The control system of claim **10** wherein said voltage of said output is a direct current voltage.

14. The control system of claim **10** wherein said first current equals said second current; and wherein said at least one sensor is a sensor providing a sensed current value from the first current or the second current of said output.

15. The control system of claim **10** wherein said first current is different from said second current; and wherein said at least one sensor is a pair of sensors providing a pair of sensed current values from the first current and the second current of said output.

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